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(54) Title: METHOD AND PLANT FOR SEPARATION OF CO_2 FROM THE EXHAUST FROM COMBUSTION OF CARBONACEOUS MATERIAL

(57) Abstract: A method for separation of the exhaust gas from a combustion plant, wherein the exhaust gas from the combustion plant is cooled and carbon dioxide is separated from the exhaust gas by bringing the cooled exhaust gas in contact an absorbent, the unabsorbed gas is removed as a carbon dioxide depleted stream that is released into the surroundings and the absorbent is regenerated to give a carbon dioxide rich stream that is collected for depositing or other use, wherein the exhaust from the combustion plant is pressurized to a pressure of at least 3 bara before it is brought in contact with the absorbent, is described. A plant for performing the method is also described.

METHOD AND PLANT FOR SEPARATION OF CO_2 FROM THE EXHAUST FROM COMBUSTION OF CARBONACEOUS MATERIAL

Invention's field

The present invention relates to a method and a plant for absorption of CO_2 from the exhaust gas from a combustion plant for combustion of fossil or other organic fuels, to separate the exhaust gas from the combustion plant into a CO_2 rich fraction and a CO_2 depleted fraction.

Background to the invention

The increase of the concentration of CO_2 in the atmosphere due to the combustion of fossil fuels, such as oil, gas and coal, in the last years has attracted increased attention because of the contribution of carbon dioxide to the greenhouse effect and thereby to global warming. Countries are obliged by international treaties to commit to a reduction in CO_2 discharges while, at the same time, the most relevant energy carriers are fossil fuels.

Several solutions have been suggested to separate CO_2 from the exhaust gas of combustion plants to reduce the discharges of CO_2 to the atmosphere by safely fixing or depositing this gas. However, such a separation of CO_2 is very difficult and requires complicated and costly equipment not least because of the large amounts of gas in question and the relatively low concentration of CO_2 in the exhaust gases from traditional combustion plants.

This situation is difficult due to the large and increasing global need for energy and fossil fuels being so readily available.

Thus, an energy efficient, cost-effective, robust and simple method for the removal of a substantial part of CO_2 from the exhaust gas to ease this situation would be desirable. The separated CO_2 can be deposited in, for example, oil reservoirs, aquefiers or possibly be dissolved in seawater and be released at great ocean depths or also be fixed chemically and be deposited. Furthermore, CO_2 can be supplied for industrial applications. Exhaust gas from power stations typically contain from around 2 to 10%

by volume CO_2, where the lowest values are typical for gas turbines, with the higher values being typical for combustion chambers in which there is nearly complete utilisation of oxygen.

Today, it is common to ignore any environmental problems and release the combustion gas into the atmosphere.

The alternatives comprise new and often costly technology and today are either being evaluated or are under development. The following alternatives can be mentioned:

- The discharge gas from the combustion is brought into contact with a chemical solution, typically an amine solution at, or near, atmospheric pressure. Some of the CO_2 is absorbed in the solution which is then regenerated in a regeneration plant to give the original chemical solution as well as a gas with a relatively high CO_2 content. Such processes are burdened with problems in connection with the size of the devices which brings the gas into contact with the chemical solution, pollution of the combustion gases that are enriched in the chemical solution and also degradation of the chemical solution. Furthermore, the regeneration is energy demanding. These problems make this process costly and complex.
- Conversion of the fuel that contains carbonaceous compounds, to hydrogen and carbon dioxide. Here, processing units called reformers are used. The reforming is an energy demanding process where hydrogen and CO_2 are formed, and CO_2 and hydrogen can thereafter be separated so that CO_2 can be deposited or taken care of in another way than that outlined above, and the hydrogen can be used as fuel. The hydrogen is then combusted in a gas turbine in a power plant. Thus, the whole plant is complicated and costly, as it comprises both a hydrogen generating plant and a power plant.
- By separating the air that enters a combustion plant into oxygen and nitrogen, the total amount of gas that is to be treated can be reduced considerably as the discharge gases from the combustion plant will be mainly composed of water and CO_2. Although it is relatively easy to separate these two components, the total costs for such a system is relatively high, as one must have an oxygen generation plant in addition to the power plant.

Thus there is a need for a method and a plant that overcome the mentioned problems.

Summary of the invention

According to a first aspect of the present invention, a method for separation of the exhaust gas from a combustion plant for carbonaceous fuel is provided, wherein the exhaust gas from the combustion plant is cooled and carbon dioxide is removed from the exhaust gas by bringing the cooled gas into contact with an absorption agent where the non-absorbed gas is led away as a carbon dioxide-depleted stream which is discharged into the surroundings and the absorbent is regenerated to give a carbon dioxide-rich stream which is collected to be deposited or for other applications, where the exhaust gas from the combustion plant is compressed to a pressure of at least 3 bara before it is brought into contact with the absorbent.

With the exhaust gas being compressed before it is brought into contact with the absorbent, the partial pressure of the carbon dioxide is increased, something which results in the absorbent being able to take up larger amounts of carbon dioxide per unit volume. This makes it possible to build smaller contact devices, wherein the absorbent is brought into contact with the exhaust gas, something which again reduces construction costs.

It is preferred that the combustion gas is compressed to a pressure of at least 8 bara, preferably more that 10 bara, for example, to a pressure of around 16 bara, before it is brought into contact with the absorbent. Increasing pressure increases the capacity of the absorbent to absorb carbon dioxide. However, compressing has an energy cost. Within the given pressure range, one obtains a good compromise between increased absorption capacity and energy cost.

The carbon dioxide depleted stream is preferably heated by heat exchange against the incoming exhaust gas from the combustion plant and that the heated carbon dioxide-depleted stream is expanded across a turbine to give at least a part of the energy that is

required for the compression of the exhaust gas, before the exhaust gas is discharged into the surroundings.

This makes it possible to utilise the energy in the incoming exhaust gas as at least a considerable source of energy for the compression of the exhaust gas.

It is preferred that water is added to the carbon dioxide-depleted stream before this is heat exchanged against the incoming, untreated, hot, exhaust gas. By adding water to the carbon dioxide-depleted stream, the heat capacity of the stream increases and thereby the ability to cool down the incoming exhaust gas and to take up heat from this.

According to a second aspect of the present invention, a plant is provided for separation of the exhaust gas from a combustion plant for carbonaceous fuel where the plant comprises means for cooling the exhaust gas from the combustion plant, an absorption device where the exhaust gas is brought into contact with an absorbent for carbon dioxide in an absorption device, means to lead the non-absorbed gas away from the absorption device as a carbon dioxide-depleted stream, a regeneration cycle wherein the absorbed carbon dioxide is separated from the absorbent to form a carbon dioxide-rich fraction and also means to collect and possibly deposit the carbon dioxide-rich stream, wherein the plant also comprises means for compressing the exhaust gas from the combustion plant to a pressure above 3 bara before the exhaust gas is brought into contact with the absorbent.

It is preferred that the plant comprises means to heat exchange the incoming, untreated, hot, exhaust gas from the combustion plant with the carbon dioxide-depleted stream to cool the incoming, exhaust gas and heat up the carbon dioxide-depleted stream, a turbine over which the carbon dioxide-depleted, heated stream is expanded before it is discharged into the surroundings, and also means to supply energy from the turbine to the means for compression of the exhaust gas.

Furthermore, it is preferred that the plant comprises means for adding water to the carbon dioxide-depleted stream before this is heat exchanged against the incoming, untreated, hot, exhaust gas.

It is preferred that the turbine is arranged on a common shaft with one or more compressors for compression of the exhaust gas from the combustion plant.

Short description of the figures:

The invention will be further described below with reference to the enclosed figures, in which:

Figure 1 shows a principle diagram of a preferred embodiment of the present invention.

Detailed description of the invention

Figure 1 is a principle diagram that shows a preferred embodiment of the present invention where an absorption plant 1 is connected to a thermal power plant 2.

The thermal power plant in the embodiment shown is a traditional, gas-fired, thermal power plant where the fuel, in the form of a hydrocarbon gas, such as natural gas, LNG, or the like, is supplied via a gas supply 3 and air (or oxygen enriched air) is supplied via air supply 4. The air from air supply 4 is compressed in a compressor 5, mixed with the gas from the gas supply 3 in a pipe 6 and led to a burner 7 where the mixture of gas and air is combusted at a temperature normally in the range 850 to 1200 °C. Normally, the compressor 5, the burner 7 and the turbine 10 are built together in one unit.

The hot combustion gas from the burner 7 is led via a line 8 to a turbine 10 where it is expanded. The turbine 10 appropriately drives the compressor 5 and a generator 11 that sit on a shaft which they have in common with the turbine 10.

The expanded gas from the turbine 10 is led by way of a line 12 to a heat exchanger 13 where the exhaust gas is cooled and where steam is generated for other purposes. The cooling down in the heat exchanger 13 and thereby the generating of steam can be

adjusted to optimise the total process. An exhaust gas line 14 constitutes the link between the thermal power plant and the present absorption plant 1.

The expanded gas in the exhaust gas line 14 is first led through a heat exchanger 20 and cooled down. Preferably, the gas is cooled down in more than one step as shown in figure 1 where the gas, after the heat exchanger 20, is led in a line 21 to a second heat exchanger 22 and from there, via a line 23, to a possible trim cooler 24 where the gas is cooled down towards the ambient temperature, for example, against water. After cooling down in the heat exchangers 20, 22, and possibly 24, water is removed from the exhaust gas in a scrubber 25, wherein condensed water is led away in a line 52. The expanded and cooled gas is led from the scrubber 25 via a line 26 to a compressor 27 where it is compressed from a pressure near the ambient pressure (1 bar) to, for example, around 4 bar. However, the exit pressure from the compressor can vary within a wide range without this being significant for the invention.

The compressed gas, which has been heated during the compression, is led in a line 28 to a heat exchanger 29. From the heat exchanger 29, the cooled gas is led via a line 30 and possibly via a trim cooler for further cooling before it is led into a scrubber 32 where water condenses and is removed from the gas. The gas is led further in a line 33 to a compressor 34 where it is compressed further, for example up to 30 bara or 16 bara. The compressing which here goes over two steps, can be carried out in a one step or several steps. The temperature in the gas increases during the compressing. Standard compressors permit an outlet temperature from the compressor of around 200 °C. Compressors which tolerate a higher outlet temperature, are considerably more costly than standard solutions. Therefore, it is preferred to carry out the compressing of the gas in several steps, such as described here with two steps with cooling in between. However, the number of steps here is a question of size which can vary from plant to plant.

Condensed water is led in a line 53 together with the water in line 52 and pumped by a pump 55 via a line 56 through a heat exchanger 36. Additional water can be supplied to pump 55 from a water supply 57 to increase the amount of water in line 56 and thereby

enable it to take up more heat in the heat exchanger 36. Water that is heated in the heat exchanger 36 is led in a line 48 to heat exchanger 20.

The cooled gas is led from the scrubber 32 in a line 33 to a new compressor 34. The compressed and heated gas from compressor 34 is led in a line 34 to heat exchanger 36 where it is cooled down, and from there via a line 37 through a possible trim cooler 38 for further cooling before it is led in a line 39 to a contact device 40 where the gas is brought into contact with an absorbent. The absorbent is preferably water, carbonate or amine, most preferably water, which is supplied to the contact device from a line 78. Gas that is not absorbed by the absorbent in the contact device 40 is led out of the contact device via line 41.

The gas stream in the line 41 is split into one stream in a line 42 and one in a line 43. Added to these gas streams is water from water supplies 45 and 44, respectively, before they are led through the heat exchangers 29 and 22, respectively, for cooling of the exhaust gas from the combustion plant. The heated gas streams from the heat exchangers 29 and 22 are led together with water from the streams in the lines 52 and 53, and further heated in a heat exchanger 20 before the combined and heated stream is led to a turbine 50 where it is expanded before it is led out through an exhaust gas outlet 51.

The turbine 50 preferably sits on a shaft 56 in common with the compressors 27 and 34. A motor 54 is also located on this shaft 56 to provide any additional energy required to drive the compressors 27 and 34.

The absorbent, which in the absorption device is at a pressure of at least 3 bara, more preferred above 10 bara, and below 30 bara, more preferred below 20 bara, for example, around 16 bara, is desorbed at pressure reduction which preferably is carried out over several steps.

In the first step, the absorbent with absorbed carbon dioxide is taken out through a line 60 and expanded first over a turbine 61 to a pressure of around 1 bara. The expanded

absorbent is led in a line 62 to a scrubber 63 where desorbed carbon dioxide is taken out through a carbon dioxide outlet 64, while the absorbent is taken out through a line 65 where it is expanded in the second step across a reduction valve 66 to a pressure of typically 0.3 – 0.5 bara and is fed into a scrubber 67. Desorbed carbon dioxide from the scrubber 67 is led via a line 68 to a compressor 69 where it is compressed to a pressure of 1 bar or more before it is led away via a carbon dioxide outlet 70.

The absorbent is led from the scrubber 67 via a line 71 and across a reduction valve 72 where it is expanded in the third step to a pressure of around 0.1 – 0.2 bara, dependent on how much CO_2 which is to be removed, before it is fed to a scrubber 73 for removal of as much as possible of the remaining absorbed carbon dioxide. Desorbed carbon dioxide is removed from the scrubber via a line 74 to a compressor 75 where the carbon dioxide is compressed to a pressure of 1 bar or more and is led away through a carbon dioxide outlet 76.

After the carbon dioxide is desorbed from the absorbent, the absorbent is led away in a line 77 via a pump 78 that increases the pressure in the absorbent to the working pressure of the absorption device 40, before the absorbent is returned to the absorption device 40 via line 79. Loss of absorbent in this circuit can be made up by supply of a new absorbent via a supply line 80. The pump 78 is preferably driven at least partly by turbine 61.

The desorbing of carbon dioxide as described above, is carried out over three steps. By desorbing, and thus generating the absorbent over several steps, one obtains a more effective desorbing and furthermore a largest possible amount of carbon dioxide is taken out at a highest possible pressure to reduce the need for subsequent energy demanding compressing. Therefore, the desorbing can, if required, be carried out over more or fewer steps than three. This is a question of optimisation which is dependent on several factors of a technical and economic matter.

The carbon dioxide from the carbon dioxide outlets 64, 70 and 76 can be brought together and sent away to be used somewhere else or deposited. For example, the

carbon dioxide can be led to a gas and/or oil field and be injected to increase the pressure in a reservoir and thus increase the production from the reservoir. However the carbon dioxide can also be used for other purposes where there is a need for carbon dioxide in production processes and the like. However, the use of and/or depositing of carbon dioxide is not a part of the invention and has no limiting influence on this.

To optimise the energy recovery in the absorption plant 1 it is very desirable that the gas that is led to turbine 20 is as rich in energy as possible. This energy is present in the form of pressure, volume flow and temperature, where temperature and volume flow are connected in that a high temperature leads to a high volume flow. The burner 7 works at 10 – 30 bara. The gas is expanded to about atmospheric pressure across the turbine 10. The inlet stream to the absorption plant in the exhaust gas line 14 has therefore a near atmospheric pressure while the absorption device works at a pressure of 3 to 30 bara, for example, around 16 bara and at a temperature in the range 5 to 30 °C. The exhaust gas from the combustion plant must therefore both be compressed to the working pressure for the absorption device 40 and be cooled to its working temperature and again be heated before it is expanded across the turbine 50. To ensure that as much as possible of the heat is recovered over the heat exchangers, it is important that the cooling gas has the largest possible capacity to take up heat. The amount of gas that goes through the absorption device without being absorbed constitutes a smaller amount of gas than the exhaust gas from the burner 7 as CO_2 is removed from the gas. The capacity to take up heat is therefore reduced in relation to the total amount of gas from the burner.

Addition of water to the relatively dry gas from the absorption device 40 increases the capacity of the gas to take up water in evaporation. Water has, at the relevant pressure, a boiling point of the order 200 to 210 °C. By adding a small amount of water only, the partial pressure of water will be so small in the total gas stream that the evaporation temperature for the water can be reduced to 50 – 100 °C, something which makes it possible for the gas to take up heat at such low temperature. This evaporation increases the total energy in the gas and thereby also the turbine's effect considerably.

The absorption plant illustrated according to the present invention operates on the exhaust gas outlet from the gas turbine at a gas power plant. The plant has application at outlet temperatures from the gas turbine from 100 to 500°C, preferably 300 to 400 °C and is best suited for new, highly effective, gas power plants with relatively low exhaust gas amounts at high temperature.

Example

The following values have been found for a gas power plant where the amount of gas in the exit gas is about 80 kg/s, with a CO_2 content of 3-5% by volume and the temperature is of the order 300 to 400 °C.

The exit gas from the exhaust gas outlet 12 is cooled to a temperature of about 30 °C with the aid of the heat exchangers 20 and 22 and also the possible trim cooler 24. The trim coolers cool the gas against the cooling water that is let out from the system while the heat exchangers transfer the heat to gas from the CO_2-depleted stream. Thereafter, the cooled gas is compressed with the help of compressor 27 to around 4 bara, something which results in the temperature of the gas rising to about 200 °C. This gas is again cooled with the help of a heat exchanger 29 and a trim cooler 31 to 30 °C before it is compressed with the help of a compressor 34 to around 16 bara. This leads to a temperature increase to about 200 °C. The gas is thereafter cooled with the help of a heat exchanger 36 and a trim cooler 38 to a temperature of 20 to 25 °C.

In the absorption device 40, about 90% of the CO_2 that is present in the gas is absorbed in water in an amount of around 8000 kg/s at around 10 °C. Pressurised water is added in an amount of from 5 to 15 kg/s from water inlets 44 and 45 to the nearly CO_2- free exhaust gas that is taken out from the absorption device 40. The CO_2-depleted stream that is added water is heated in heat exchanger 22 to a temperature of around 110 °C and in heat exchanger 29 to a temperature of around 170 °C, respectively, before the streams from the heat exchangers are mixed with water from the scrubbers 25 and 32, that together constitute around 3 kg/s.

The combined stream is thereafter led through the heat exchanger 20 where it is heated to around 340 °C or around 10 °C to 30 °C lower than the temperature of the incoming, untreated, exhaust gas from the thermal power plant. The heated, treated, exhaust gas in a line 49 is expanded across the turbine 50 to give around 28 to 29.5 MW. This energy is used to drive the compressors 27 and 34. In the plant illustrated, the total compression work for 80 kg/s exhaust gas and an absorption pressure of 16 will only require around 30 MW. The difference, 1.5 to 2 MW is supplied with the help of motor 54. Without injection of water in the CO_2-depleted stream before it is heated in the heat exchanger 20, the effect of the turbine 50 will be reduced to about 2.5 MW, something that constitutes a reduction of close to 10%.

The present invention is described with reference to a preferred embodiment. An expert will understand that many adjustments and alterations are possible without departing from the inventive concept. For example, the plant described is for use in connection with a gas power plant. It will also be possible to couple the present absorption plant with other types of combustion plants, such as for example, a coal-fired power plant.

C l a i m s

1.

Method for separation of the exhaust gas from a combustion plant for carbonaceous fuel, wherein the exhaust gas from the combustion plant is cooled and carbon dioxide is removed from the exhaust gas by bringing the cooled exhaust gas into contact with an absorbent where the non-absorbed gas is led away as a carbon dioxide-depleted stream that is released into the surroundings and the absorbent is regenerated to give a carbon dioxide-rich stream which is collected for deposition or for other applications, c h a r a c t e r i s e d i n that the exhaust gas from the combustion plant is compressed to a pressure of at least 3 bara before it is brought into contact with the absorbent.

2.

Method in accordance with claim 1, c h a r a c t e r i s e d i n that the combustion gas is compressed to a pressure of at least 8 bara, preferably more than 10 bara, for example, to a pressure of around 16 bara, before it is brought into contact with the absorbent.

3.

Method in accordance with claim 1 or 2, c h a r a c t e r i s e d i n that the carbon dioxide-depleted stream is heated by heat exchanging against the incoming exhaust gas from the combustion plant and that the heated carbon dioxide-depleted stream is expanded across a turbine to provide at least a part of the energy that is required for the compression of the exhaust gas before the exhaust gas is released into the surroundings.

4.

Method in accordance with claim 3, c h a r a c t e r i s e d i n that water is added to the carbon dioxide-depleted stream before this is heat exchanged against the incoming, untreated, hot, exhaust gas.

5.

Plant for separation of the exhaust gas from a combustion plant (2) for carbonaceous fuel where the plant comprises means to cool the exhaust gas from the combustion plant

(2), an absorption device (40) where the exhaust gas is brought into contact with an absorbent for carbon dioxide in an absorption device (40), means to lead the non-absorbed gas away from the absorption device as a carbon dioxide-depleted stream, a regeneration cycle where the absorbed carbon dioxide is separated from the absorbent to give a carbon dioxide-rich fraction and also means for collection and possible deposition of the carbon dioxide-rich stream,
c h a r a c t e r i s e d i n that the plant also comprises means (27, 34) for compressing the exhaust gas from the combustion plant (2) to a pressure above 3 bara before the exhaust gas is brought into contact with the absorbent.

6.
Plant according to claim 5, c h a r a c t e r i s e d i n that it comprises means for heat exchanging the incoming, untreated, hot, exhaust gas from the combustion plant with the carbon dioxide-depleted stream to cool the incoming exhaust gas and heat up the carbon dioxide-depleted stream, a turbine (50) across which the carbon dioxide-depleted, heated stream is expanded before it is released into the surroundings, and also means to provide energy from the turbine (50) to the means (27, 34) for compressing the exhaust gas.

7.
Plant according to claim 6, c h a r a c t e r i s e d i n that it comprises means to add water to the carbon dioxide-depleted stream before this is heat exchanged against the incoming, untreated, hot, exhaust gas.

8.
Plant according to claim 6 or 7, c h a r a c t e r i s e d i n that the turbine (50) is arranged on a common shaft with one or more compressors (27, 34) for the compressing of the exhaust gas from the combustion plant (2).

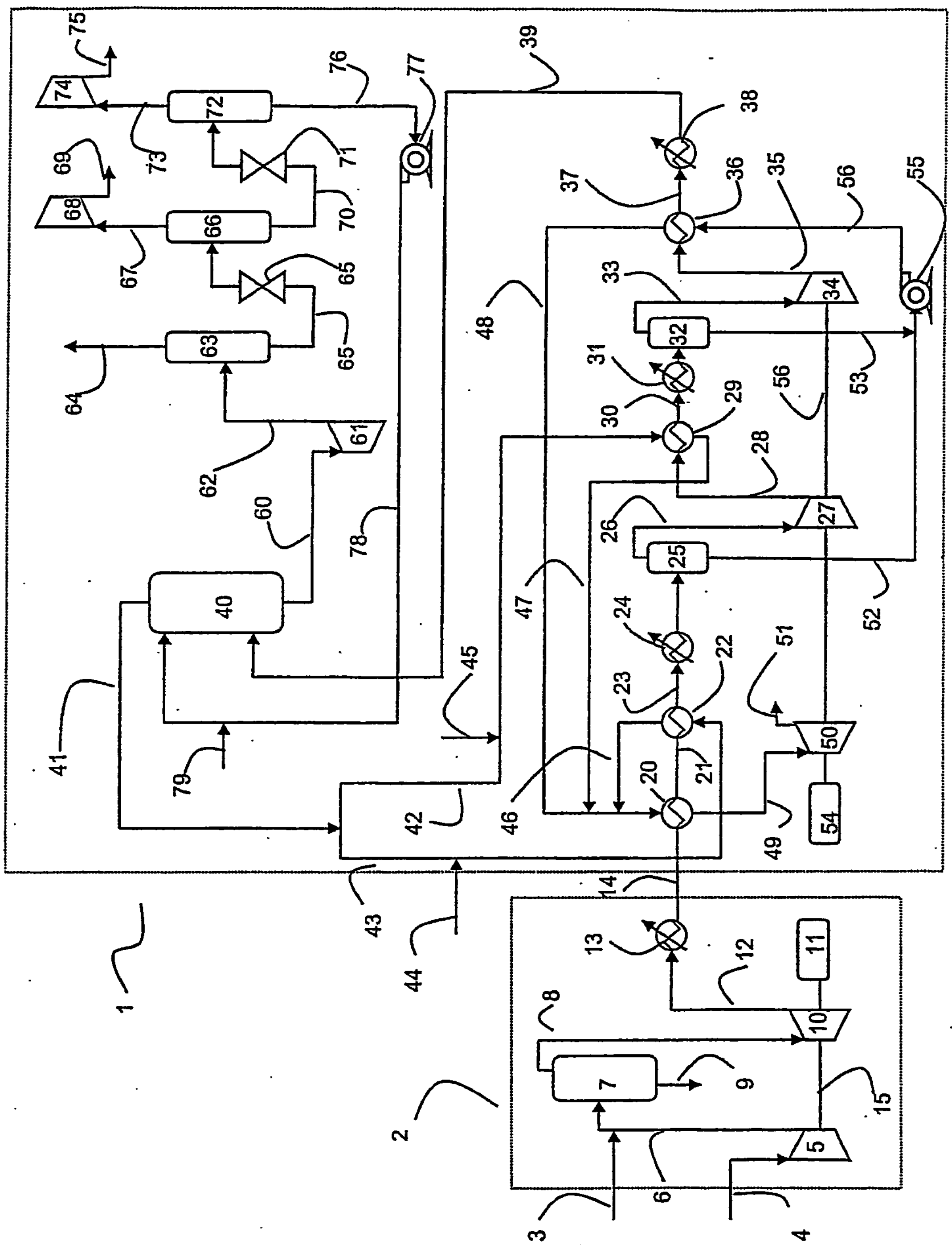
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Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 03/00320

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: B01D 53/62, B01D 53/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 0048709 A1 (NORSK HYDRO ASA), 24 August 2000 (24.08.00) --	1-8
A	WO 0057990 A1 (CHRISTENSEN PROCESS CONSULTNG AS), 5 October 2000 (05.10.00) -- --------	1-8

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

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"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 December 2003	22 -12- 2003
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Bertil Dahl/ELY Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

31/10/03

International application No.
PCT/NO 03/00320

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		AU 2332500 A	04/09/00
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